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Constraints on the effective utilization of wind power in China: An illustration from the northeast China grid

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ABSTRACT

Even though China's wind power industry has experienced a rapid growth since the beginning of this century, the utilization of wind power is still worrisome. In 2010, about 30% of China's total installed capacity could not get access to the grid. And about 10% of China's total wind power generation was curtailed. The problem of wind power curtailment is more prominent in Northeast-China region. The main particularity of Northeast China Grid is as follows: during the long heating period in winter, combined heat and power thermal plants need to modify the turbine generator's output to meet the heating demand and thus the thermal power peak regulation capacity is reduced, as a result the barriers of wind power consumption are increased. This paper provides a new perspective of the constraints on the effective utilization of wind power in the Northeast China Grid. We argue that there are two categories of constrained factors: structural factor and operational factor. The former includes grid structure, wind source structure, power source structure, and market structure. The latter includes power price mechanism, dispatch mode arrangement, wind power integration codes, and wind power forecast. At last, we make policy recommendations: promote the coordination between wind farm investment and grid construction, strengthen interprovincial power trade mechanism, implement flexible pricing mechanisms as well as improve current dispatch mode, etc.

Contents

1. Introduction

As climate change becomes an increasingly pressing concern, China now is facing many challenges from the extensive use of fossil energy resources [1], such as the mounting international

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and domestic pressures to cut back CO_2 emission [2]. Hence, it is imperative for China to promote renewable energy development. China is rich in wind resources. According to the China Meteorological Administration, onshore wind power resources at an altitude of 10 m total about 3226 GW in terms of electricity, of which 253 GW is available for development and utilization [3]. The development of China's wind power was initiated in the 1980 s, represented by the establishment of China's first demonstration wind farm with imported units, Malan Wind Farm, in Rongcheng, Shandong Province on May 8, 1986. Since then, the Chinese government has attached great importance to wind power development, and a series of policies have been formulated to promote the development of wind power, including *Regulation on Wind Farm Parallel Operation* (*Trial*), *Electric Power Law of the People's Republic of China and Program for the Development of New and Renewable Energy Source* (*1995–2010*). At the beginning of this century, China's wind power industry began to grow dramatically. From 2000 to 2005, China's installed wind power capacity increased at an annual average rate of 20% [4]. Since the promulgation of *the Renewable Energy Law* in 2005, China's installed capacity of wind power has grown dramatically, reaching 44.73 GW by the end of 2010, exceeding the target set in China's long-term energy planning for 2020 [5]. It was the first time that China surpassed the United States and ranked the first in the world in terms of installed capacity of wind power [6].

China's Northeast area is one of the three most wind-rich interiors (Northeast, North-China and Northwest) and possesses abundant wind energy reserves [7]. The Northeast China Grid ranging from Heilongjiang, Jilin, Liaoning to the East of Inner Mongolia(EIM) covers a power supply area of 1.27 million km^2, taking a share of 13 percent of the country's total power supply territory (Fig. 1). The population in this area is 121 million, accounting for 9 percent of the country's total (data at the end of 2009). Physical grid infrastructure in this area is mainly framed with 500-kV transmission lines, extended by 220-kV circular lines connecting most part of power generation units and load centers within the region. The longest transmission line of the north to south grid in this region, being linked to the North China Grid (in the Beijing and Hebei area) by a 500 KV back-to-back HVDC system, is 1643 km.

The Northeast China Grid has experienced a rapid development of wind power in recent years. Its installed capacity of wind power surged from 847 MW in 2006 to 8510 MW in June 2010, accounting for 39.12% of the nation's total, growing at double rates for three consecutive years. At present, its total installed capacity of wind power ranks the first among all Chinese regional Grids (Northeast Grid, North China Grid, Northwest Grid, Middle China Grid, East China Grid, and the South Grid). Meanwhile, the Northeast China Grid has paid much attention to wind power integration into grid, and the amount of wind power it purchased was 9.693 billion KWh at the end of 2009, an increase of 97.3% over the same period in the previous year, a proportion of 48% of the wind power purchased by the State Grid system. From January to June 2010, the cumulative wind power generation of the Northeast China Grid reached 8.557 billion KWh, accounting for 5.18% of the national total[1] , rivaling the best in China.

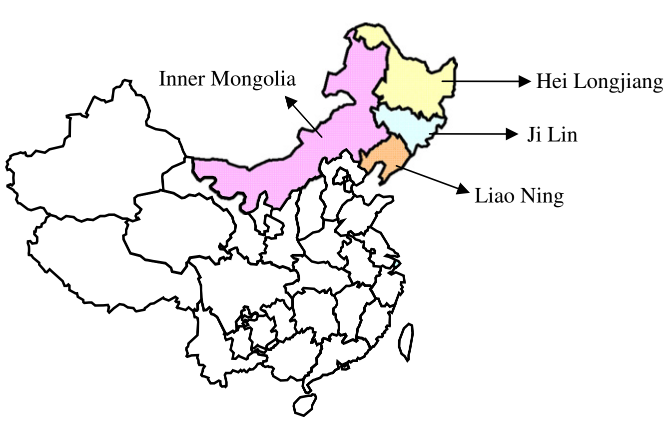


Fig. 1. Map of China with highlighted three Northeast provinces and Inner Mongolia (Northeast China Grid includes three Northeast provinces and Eastern Inner Mongolia).

Behind the successful story of wind power development, challenges exist in China [5–15], especially in the Northeast Grid. In 2010, China's grid-connected installed capacity of wind power was only 31,000 MW, which means about 30% of China's total installed capacity could not get access to the grid. According to a report by the State Electricity Regulatory Commission (SERC), in the first six months of 2010, wind power curtailment was as high as 2776 GWh, about 10% of China's total wind power generation. The problem of wind power curtailment is more prominent in the northeast China region. In 2009, the curtailed wind power generation in the Northeast China Grid was about 912 GWh, a proportion of 9.41% of the total possible wind power output[2]; in 2010, approximately 1,963 GWh wind power were curtailed, an increase of 11.33% than in 2009. The exacerbated curtailment of wind power would not only drive people away from wind power [8], but also further reduce the already fairly low efficiency of wind farms in China. Hence, it is crucial to explore the constraints on the effective utilization of wind power and find solutions for improving the low efficiency (or low "capacity factor") of China's wind farms.

Some studies have paid attention to the challenges China faces in the development of wind power, such as low quality of turbines [9–11], regulatory uncertainty and policy inconsistency [9,12], high generation cost and stagnating development of domestic manufacture [13]. A few studies explore the factors directly related to China's low efficiency of wind power including inadequate grid infrastructure which leads to power transmission congestion [6,8–11,14,15], system economics (more wind power integration would bring about more system operation cost) which leads to the fact that grid corporations dislike wind power [8,9], and huge backlogs [8] (dispatch mode adjustment, publication of codes at state level, improvement of wind power production forecasting capacity).

Although the above studies provide some valuable insights, to our best knowledge, few make particular analysis on the factors that constrain the effective utilization of wind power in China. Our study makes an attempt to fill the gap. We first analyze the current situation of wind power integration and curtailment in the Northeast China Grid, then explore the factors influencing the low efficiency of wind power from two broad aspects: one is structural factors such as grid structure, wind source structure, power source structure, and market structure; the other is operational factors such as power price mechanism, dispatch mode arrangement, wind power integration codes, and wind power forecast. At last, conclusion and policy recommendations are provided.

2. Current situation of wind power integration and curtailment in the northeast China grid

In 1993, there was only one wind farm with four units and 300 KW installed capacity in the Northeast China Grid. This situation has changed rapidly since the year 2005 (Table 1).

[1] Data source: Northeast Grid Limited Company. Report of wind power development of Northeast Grid (in Chinese), July 2010.

[2] Data source: Northeast Electricity Regulatory Authority. Annual Report of Electricity Regulatory of Northeast Region (2009) (in Chinese), 2010.

At present, several wind power units at GW level have been set up in Baicheng of Jilin province, Tongliao and Chifeng in Inner Mongolia. By June 2010, the installed capacity of wind power had reached 8510 MW, accounting for 39.12% of the country's total. And the Tongfa wind power farm in Jilin province becomes the single biggest farm with an installed capacity of 450 MW.

Table 1
Installed capacity of wind power in the Northeast China Grid over the period of 2004–2009.
Source: European Wind Power Association; Data published by the Northeast China Grid, Wang, T., Zhang X. Northeast: the second largest power source test the grid, State Grid, 2009, 11, 41.

Year	Northeast China Grid (10000 KW)	Growth rate (%)	National (10000 KW)	Percentage of the whole country (%)
2004	24	–	76.4	31.4
2005	34	41.7%	126	27.0
2006	85	150.0%	260.4	32.6
2007	137	61.2%	605	22.6
2008	298.3	117.7%	1212.1	24.6
2009	754	152.8%	2510.4	30.0

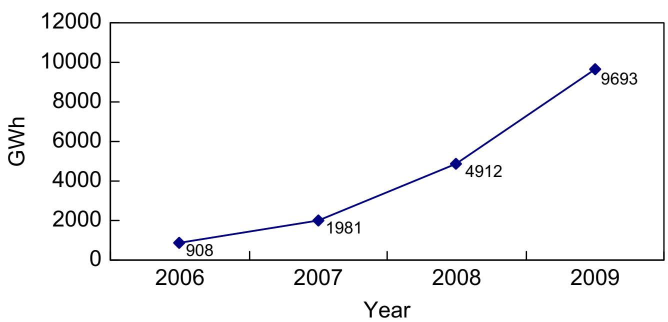


Fig. 2. Wind power generation in the Northeast China Grid (GWh).
Source: The Northeast China Grid Limited Company, 2010, 8.

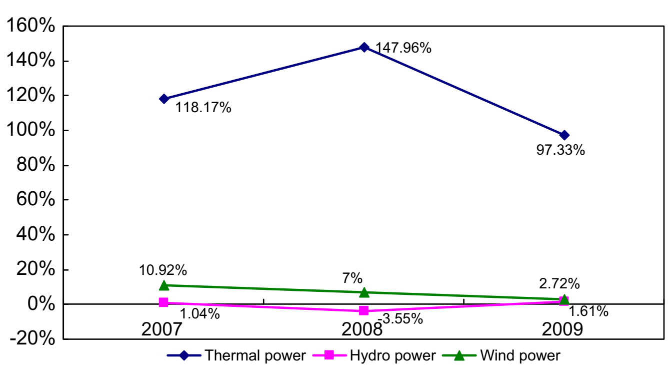


Fig. 3. Comparison of generation growth of thermal power, wind power and hydropower in the Northeast China Grid during 2007–2009.
Source: The Grid Operation Work Report in the northeast area, The Northeast China Grid Limited Company, 2010, 9.

Along with the rapid growth of installed wind power capacity, electricity generation from wind farms has increased quickly in the Northeast China Grid since 2006 (Fig. 2). Wind power generation in the grid has outgrown those of hydropower and thermal power (Fig. 3).

However, with more and more deployment of wind power, peak regulation and frequency modulation have become increasingly difficult for the Northeast China Grid since 2008. The electricity system safety has also become a big issue. Another severe problem is, as the three northeast provinces and EIM that belong to the Northeast China Grid are located in the far north of China, which is very cold in winter (the heating period in some of the areas even lasts for 7.5 months per year), heat supply to inhabitants must be guaranteed in winter. As an active response to the government's policy of expanding central heating areas, the proportion of combined heat and power units (CHP) soared to 50% (Jinlin Province even surpassed 90%) at the end of 2010. Consequently, the priority of CHP units in winter is to address residents' basic heating demand, power generation from thermal power plants is thus more than in summer, which leads to two negative impacts on wind power integration: first, under the situation where power demand is limited (as in the case of the Northeast China Grid), more thermal power output means less wind power output; second, the peak regulation capacity of thermal power plants is reduced, bringing about more difficulties of wind power integration in the Northeast China Grid in winter.

Since 2008, the Northeast China Grid has initiated the curtailment of wind power and the situation of curtailment has deteriorated. 119 million KWh, 912 million KWh and 1.963 billion KWh of wind power were curtailed in 2008, 2009 and 2010 respectively. Table 2 further shows the situation of severe wind power curtailment in the Northeast China Grid in the year 2009.

3. Constraints on the effective utilization of wind power in the northeast China grid: structural factors

3.1. Grid structure is weak, especially in the areas with rich wind resources

The transmission lines of 500-KV are limited in the Northeast China Grid, which leads to electromagnetic loop sometimes. In the meantime, the issue of short circuit of 220 kV line is also prominent. On the other hand, the areas with rich wind resources such as Baicheng in Jilin Province, Chifeng and Tongliao areas in EIM are obviously lack of transmission capacity to deliver and transmit power. Table 3 demonstrates that the Northeast China Grid suffered a huge loss of wind power of 92,469 MWh from January to July 2010 due to the weak network structure.

Table 2
Wind power curtailment in the Northeast China Grid in 2009.
Source: The Market Department of the Northeast China Electric Power Supervision, August 2010.

Area	Wind farm capacity: KW	Grid-connected electricity: 10,000 KWh	Limited times	Electricity loss in 2009: 10,000 KWh	Electricity loss in 2008: 10,000 KWh	Growth rate: %
Liaoning	1923710	258295	436	1694	83	1940
Jilin	1526510	211064	22982	21947	2369	827
Hei Longjiang	1345500	195568	778	11477	1093	950
EIM	2604410	271492	908	53239	8341	538
Total	7400130	936418	25104	88358	11886	643

Table 3
Curtailed wind power in the Northeast China Grid caused by weak grid structure from January to July 2010.
Source: Report on the Wind Power Research of the Northeast China Grid, the Northeast China Grid Company Limited, August 2010.

Northeast Grid		EIM		Liaoning		Jilin		Hei Longjiang	
Times	Power loss: MWh	Times	Power loss: MWh	Times	Power loss: MWh	Times	Power loss: MWh	Times	Power loss: MWh
187	92469	134	68771	2	187	134	92469	2	68771

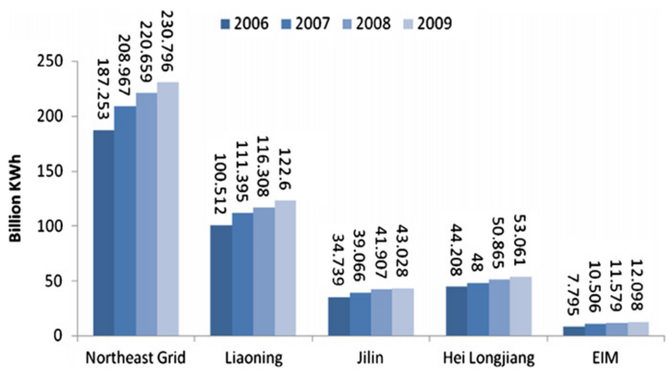


Fig. 4. Power demand change of the Northeast China Grid during the period of 2006–2009.
Source: The Northeast China Grid Limited Company, 2009; NERA, 2010, 5.

3.2. Wind resources are concentrated and far away from load centers

The exploitable wind resources with available technology amount to 29.7 GW in the northeast region, accounting for 11.71% of the country's total. However, these abundant wind resources are mainly distributed in Chifeng in EIM area, Tongliao and Baicheng areas in Jilin Province, and the eastern area of Heilongjiang Province [16], which are all far away from load centers.

In 2009, Liaoning Province, an electricity load center in the Northeast China Grid, consumes 51% of the grid's total power, however, wind power connected to the Liaoning grid took a share of only 25.52% of the grid's total; by contrast, in the EIM, a wind abundant area had a share of 31.90% of the total grid-connected wind power, only accounted for 5.24% of the total electric consumption in the grid. Fig. 4 further shows that the loads that increased the most were also in Liaoning province. The imbalanced distribution between wind resources and load centers implies that the Northeast China Grid faces big challenge for promoting wind power utilization.

3.3. Power source structure being dominated by coal-fired power plants makes peak regulation difficult

The power source structure of the Northeast China Grid is dominated by thermal power which accounts for more than 80% of total power source installation (Table 4), and most of the thermal power is generated from coal-fired power plants. Meanwhile, due to the increase of CHP units and the corresponding dramatic decline in peak regulation capacity resulted from the minimum power generation requirement for meeting the basic needs of heating supply, wind power output had been more restricted during the heating periods in recent winters.

In addition, with the implementation of the "substituting small scale thermal power plants with large scale ones" policy many power plants under 100 MW have been closed up. Hence, the start and stop capacity of peak regulation is much weaker, which becomes another constraint significantly influencing the effective utilization of wind power in the grid.

Table 4
Proportion change of power source structure of the Northeast China Grid during the period of 2006–2009.
Source: Data of 2007—2008 are from Northeast China Grid Operation, Northeast China Grid Company Limited; data of 2009 is from Northeast Area Grid Operation Work Report, Northeast Electric Power Supervision Bureau.

	Thermal power (%)	Hydropower (%)	Wind power (%)	Others (%)
2006	85.17	13.02	1.78	0.03
2007	86.22	11.18	2.46	0.13
2008	84.55	10.42	4.73	0.30
2009	81.60	9.26	8.78	0.36

Lastly, the installed hydropower capacity proportion and the relative power generation currently take on a declining trend (Fig. 2). In 2009, the installed hydropower capacity accounted for only 9.26% of the total. Meanwhile, the reservoirs in the Northeast China Grid have undergone low flow for many years. Statistics show that, during the thirteen years from 1997 to 2009, except one high water period in 2005, the reservoirs had experienced low water periods as long as 12 years, which has greatly influenced the peak regulation capacity of hydropower units, and has led to more difficulties for wind power integration and utilization.

3.4. Power market is comparatively closed and interprovincial real wind power trade does not exist

The imbalance between wind resources and load centers implies that the trade of wind power across provinces (or areas) is crucial to promote wind power utilization. However, the current power market structure is unfavorable for interprovincial real wind power trade in that:

(1) China's electric power market conducts the regulation which is based on a single province, namely electricity supply and demand should in principle seek self-balance within a specific province itself.. The policy of not allowing wind power to be delivered out of province has limited wind power trade across provinces. Such policy originates from the differentiated feed-in tariffs applied in different provinces in China. Further discussion in this respect is made in Section 4.1.
(2) Under the current China's power market structure, trans-regional power trade (China's power market is divided into six parts, including the Northeast, North China, Northwest, East China, central China and South) is more difficult than trans-provincial power trade. The current limited power exchange across the above six regions is mainly based on plan-oriented mechanism instead of price-signaled market mechanism. The practice of countries with high proportion of wind power integration such as Denmark, Spanish proves that opening power market, namely expanding power exchange across countries or regions, is one of the crucial conditions to guarantee wind power feed into grid with high proportion. Hence, the closed market structure either for intra-provinces

or for intra-regions is one of the most significant constraints on the effective utilization of wind power in China.

(3) There are several imperfections in current power market trade mechanism which also limit the possible wind power trade across provinces or regions: Firstly, it is too hard to reach an agreement on power transmission price across provinces. Since interprovincial transmission price has not officially been approved by the government, it has to be negotiated between the seller and the buyer, which turns out to be a tough work. Secondly, network loss cannot be compensated. As power grid utilities which transmit electricity across provinces obtain no compensation for network loss, they have no enthusiasm to promote trans-provincial electric power trade. Thirdly, electricity trading volume, based on enterprises' own decision, is relatively limited. In the existing interprovincial power trade mechanisms, most proportions of power exchanged across provinces are distributed by planned measures.

4. Constraints on the effective utilization of wind power in the northeast China grid: operational factors

4.1. Feed-in tariffs are unfavorable for promoting wind power utilization to some extent

Current feed-in tariff mechanisms obstruct wind power integration and utilization to some extent. First, feed-in tariffs are set according to various wind resources situation, preventing the trans-provincial (or regional) trade of wind power. According to the *Notice on Improving On-grid Wind Power Prices Policy* (SDRC, Price [2009] No. 1906) promulgated by the State Development and Reform Commission (SDRC) in 2009, the whole country is divided into four categories of wind resources areas, and accordingly four corresponding wind power benchmark feed-in tariffs—RMB0.51/KWh, RMB0.54/KWh, RMB0.58/KWh and RMB0.61/KWh are stipulated:. In the Northeast China Grid, different provinces belong to different wind resources areas and various feed-in tariffs are applied. Hence, it is difficult to conduct trans-provincial wind power trade in either the Northeast China Grid or other regions in the country.

Second, a completely fixed price mechanism cannot manifest wind power's competitive advantage of low running cost. The implementation of feed-in tariff of wind power plays a positive role in guaranteeing wind power enterprises' benefit and promoting wind power development at the initial development stage. However, with the rapid development of wind power and the increasing growth of wind curtailment proportion, the completely fixed price does not agree to the expanding utilization of wind any more. Under the new context, if flexible price could be introduced, as in Spain, Denmark, New Zealand, and England [17], the amount of wind power curtailment would be less.

4.2. Dispatch mode fails to take full consideration of wind power integration

Currently, the dispatch mode conducted by the Northeast China Grid is "unified dispatch, and control at different levels". This dispatch mode fails to take full consideration of wind power integration: first, from a macroscopic perspective, this dispatch mode is based on the requirement of self-balance in a single province. As previously discussed, the power demand in the areas with abundant wind resources such as Jilin Province and EIM area is limited. As a result, the system capacity of expanding wind power utilization is undermined.

Second, less pre-consideration of wind power generation is taken when determining the start-up mode and production of power units (which power units should produce and how much output each power unit should have). Instead of being pre-considered in dispatch mode, the arrangement of wind power generation is subject to the output of other units.

Third, researches on optimum security and economy peak regulation curve are lack when thermal power units need to be made in-depth peak regulation in order to absorb more wind power into grid.

4.3. Grid codes for wind power integration at state level are lack

The lack of grid codes for wind power integration in China has led to some serious power grid accidents and become one of the prominent negative factors on wind power utilization. At present, China still lacks national-level grid codes for wind power integration. A guide program, *Technical rule for connecting wind farm to power network* promulgated in 2005 was not in force any more. Another document, *Technical rule for connecting wind farm to grid* published by the State Grid Corporation of China was in trial implementation in 2006 and revised in 2009. Since it is only a code at enterprise level, its binding force is relatively weak. The document "*Operational standards for wind power dispatch*" (Exposure Draft), China's first industrial standard for wind power integration published by the China Electricity Council in February 2011 marks a historic progress for the standards of wind power integration. However, this code is still not at state level and not enforceable

Spain, Germany and other countries with strong wind power development have established comparatively complete grid codes system for wind power integration around the year 2002 (Table 5). Spain, for example, has formulated strict technical standards for wind power integration. It is specified that new technology and control system must be adapted to newly-installed wind turbines, in the meantime wind farms should timely update the control system of old wind turbines. China's wind power industry lags behind in this respect. The imperfect grid code system for wind power integration leads to disorderly development of China's wind power industry and difficulty in wind power integration and utilization, and even causes some large-scale wind power drop-off accidents.

4.4. Wind power forecasting accuracy is low

The forecasting accuracy of wind power plays a crucial role in the expansion of wind power utilization, especially when the proportion of wind power integration reaches above 10%. By the end of 2009, the capacity of wind turbines put into operation in the Northeast China Grid was 6.27 million KWh, accounting for 8.78% of the total installed capacity, 15% and 20% of the power generated by the whole grid at peak and at valley respectively. Consequently, improving wind power forecasting accuracy of the Northeast Grid becomes crucial.

At present, the Northeast China Grid has already established wind power prediction systems with basic short-term forecasting function in Liaoning and Jilin Province. Particularly, the forecasting system of wind power has been operating for nearly 3 years in Jilin Province since the year 2008. This system is capable of forecasting power output of wind farms in the next 3 day based on historical data of power generation, weather condition and wind turbine operation status. On March 8, 2011, a technology project of intelligent power generation planning system of Jilin Grid passed the acceptance testing from the State Grid Corporation, symbolizing a critical break-through on large-scale wind power forecasting technology [18].

Table 5
Legislation frameworks related to wind power integration in Spain and Germany.
Source: Grid Codes for Wind Power Integration in Spain and Germany: Use of Incentive Payments to Encourage Grid-Friendly Wind Power Plants, http://www.efchina.org, August 2010.

	Spain	Germany
Frequency control	Enforced	Enforced (new power plants) incentive (existing plants)
Voltage control	–	Enforced (new power plants)
Reactive power supply	Incentive	Enforced (new power plants)
Through fault capability	Incentive	Enforced (new power plants) incentive (existing plants)
Consistency between unit operation and original predication	Incentive	–

Although a few progresses in the fields of wind power forecasting have been made, there is still a big gap in the forecasting capability and accuracy between China and other experienced countries. The lag in China's wind power forecasting technology, the shortage of data used for forecasting, and the scarcity of service suppliers, among others, greatly restrict the schedulability of wind power integration and limit its effective utilization.

5. Conclusion and policy recommendations

Along with the rapid development of wind power in China, China's wind power farms are underperforming, and the capacity factor (which is calculated by dividing the energy actually produced by that the installations could maximally generate) is low [8,19]. We explore the reasons hindering the effective utilization of China's wind power from the perspectives of both structural factors and operational factors based on the case study of the Northeast China Grid.

The constraints on the effective utilization of wind power caused by structural factors mainly involve: (1) the structure of the Northeast China Grid with 500 KV transmission line is relatively weak and electricity transmission capability is obviously insufficient in wind power concentration area; (2) wind resources of the Northeast China Grid is intensively distributed, and far away from load centers. (3) the proportion of coal-based power installation is too high in the Northeast China Grid; the quantity of CHP plant increases quickly; and the proportion of hydropower installation is low. This power source structure leads to weak peak regulation capacity. (4) comparatively closed market structure restricts the expansion of wind power trade.

The constraints on the effective utilization of wind power caused by operational factors mainly involve: (1) fixed and differentiated wind power pricing mechanism; (2) unified dispatch mode based on power balance within a single province, as well as little consideration about the needs for expanding wind power integration; (3) lack of grid codes for wind power integration at state level; (4) low wind power forecasting ability.

In order to further promote wind power utilization in China, we provide the following policy recommendations: (1) strengthen the coordination between the construction of wind power project and electric grid and encourage more investment in the fields related to wind power transmission; (2) promote peak regulation capacity, for example, pay more attention to the research and technology innovation of coal-fired power in-depth peak regulation, and reinforce hydropower construction for more wind power integration; (3) further push power market reform, expand the scope of wind power trade, and improve the electricity trade mechanism for promoting wind power trans-provincial and trans-regional trade; (4) implement flexible pricing to enhance wind power competitiveness and better reflect the situation of demand and supply of wind power; (5) formulate and impose grid codes for wind power integration at state level as soon as possible so as to encourage wind turbine manufacturers to implement innovative technology, and improve grid control level and management capability for more wind power integration; (6) improve the existing dispatch mode, appropriately break the rule of "maintaining self-balance of power demand and supply within single province" and give priority to wind power in dispatch planning. At the same time, better arrange the in-depth peak regulation of thermal power plants based on their optimum security and economy curve; (7) enhance wind power forecasting accuracy and emphasize the breeding of intermediaries which can provide wind power forecasting service.

In sum, it has been proved that wind energy is a good solution to providing electricity with little fossil energy consumption, and one of the best ways to mitigate climate change [20]. Improving wind power utilization and the relative capacity factor is a big challenge facing China at present and would be one of the key issues for promoting China's sustainable wind power development in the future.

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